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IMAGING THROUGH FIBERS

University of Michigan

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An image is relayed in parallel over single mode optical fiber using the principles of physical optics (Holography). This is in contrast to all conventional fiber optic signal processing, which first converts all information into a sequential stream of bits or analog data. At this stage, a bundle is used only for intensification, and the required reference signal is sent separately in free space. Future work will incorporate even these last two system components into one single mode fiber. This is the first time this has been accomplished.

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Introduction

There are two usual ways to transmit information on a fiber or fiber bundle. The signal may be treated as the optical analog of an electrical signal, and transmitted just as an electrical signal is transmitted over wire. Alternatively, an object could be imaged onto the surface of a fiber bundle, as in a fibroscope. We are concerned with other, more experimental methods. Several such methods have been suggested[1-6]. Phase conjugation is one such method. Another is to have each mode of a multichannel fiber transmit a different pixel element of the object scene. Still another is to transmit a broad band of wavelengths, with each pixel being carried on a different wavelength.

Work Accomplished

We conceived and demonstrated a method of imaging through a fiber using broad source holographic principles. Here, each element of an extended source carries a different pixel element or a different Fourier component of the image. In this method, an image can be carried on either a single fiber or a bundle of fibers. The fibers can be either single or multimode.

The basic idea is explained with the aid of Fig. 1. Light from a spatially incoherent (i.e., extended) source illuminates an object. We assume that the end of the transmitting fiber is at the back focal plane of a lens, L_1. If the illuminating source had been spatially coherent (a point source) then the object Fourier transform would be formed at the back focal plane, P_3, and one component of the Fourier transform would pass through the fiber and emerge at the other end. Of course, many Fourier components are required to form an image, and they must all be combined with exactly the right phase relationships. Now consider an extended source; such a source can be regarded as being composed of many point sources. Each component point source projects a Fourier transform to the plane P_3, but the Fourier transforms are displaced from each other, just as the point elements of the source are displaced from each other. Each point source element thus images one spatial frequency component of the object onto the fiber, thus all spatial frequency components of the object go through the fiber. However, the spatial frequency components, being incoherent with each other, cannot combine coherently to form the object spatial frequency spectrum. To overcome this limitation, a portion of the light is split off from the incident beam before it reaches the object, and is transmitted via another path to a plane P_4 near the exiting end of the fiber. The two beams are brought together to form a hologram. In the hologram recording process, the interference with the reference beam

restores the missing phases to the Fourier components, so that in the reconstruction process, all Fourier components are combined coherently, resulting in a complete, 3-D image of the original object distribution.

The theory of the process is as follows. The object- bearing beam consists of many components, one for each element of the extended source. Each component carries full information about the Fourier components of the object, and also a random phase term resulting from random fluctuations of the source element. The reference beam carries no information about the object, but consists of a component for each element of the source, including the random phase fluctuation. In the interference process between the object and reference beams, all components of the reference beam combine with all components of the object beam. When an element of the object beam combines with a reference beam element that came from a different source element, there is no correlation and the product of the two fields averages to 0 and is eliminated. An object beam element combining with a reference beam component from the same source element produces a strong correlation, hence does not average to 0. Indeed, the randomizing phase element in the beams, being perfectly correlated, averages to 1, so that the Fourier component sheds its random phase and becomes completely coherent with all the other Fourier components. Thus, the Fourier components combine to form an image, complete with phase and thus 3-dimensional.

The theory has been experimentally verified by transmitting an image through a single 12um fiber. The object consisted of three 0.2mm wires, two of them mounted 0.5cm apart in one plane (P_1), and the third mounted in another plane 5 cm from the other wires (P_2). The third wire was laterally positioned so as to be imaged in between the two wires in P_1. A hologram was recorded and the images were read out and photographed with a conventional camera. Figure 2 shows the recorded images at three different planes, along with an image of the original object (Fig. 2a) and an image of the object as seen through the fiber without the holographic process (Fig. 2b). Figure 2c is the image with plane P_1 in focus, Fig. 2d is with plane P_2 in focus and Fig. 2e is an image of a plane half way between P_1 and P_2. Clearly both the lateral-dimension information and the depth information have been preserved. We have, therefore, transmitted the complete optical field, including phase, which is the requirement for 3-D imaging. Because of insufficient power, we sacrificed resolution in one of the lateral dimensions (the vertical dimension.) This allowed the use of a

Conclusion

line source instead of a fully two-dimensionally broad source, thereby conserving light. The extension to the other lateral dimension is straightforward, requiring simply a source broad in both dimensions instead of a line source.

Conclusion

The process requires rather large levels of light input, since it is impossible to couple extended source light into a single mode fiber efficiently. However, monochromatic light of adequately high power levels is widely available, so low coupling efficiency would seem to be no problem. Next, the goal of our current research is to similarly confine the reference beam to a single fiber, instead of the free space propagation currently used.

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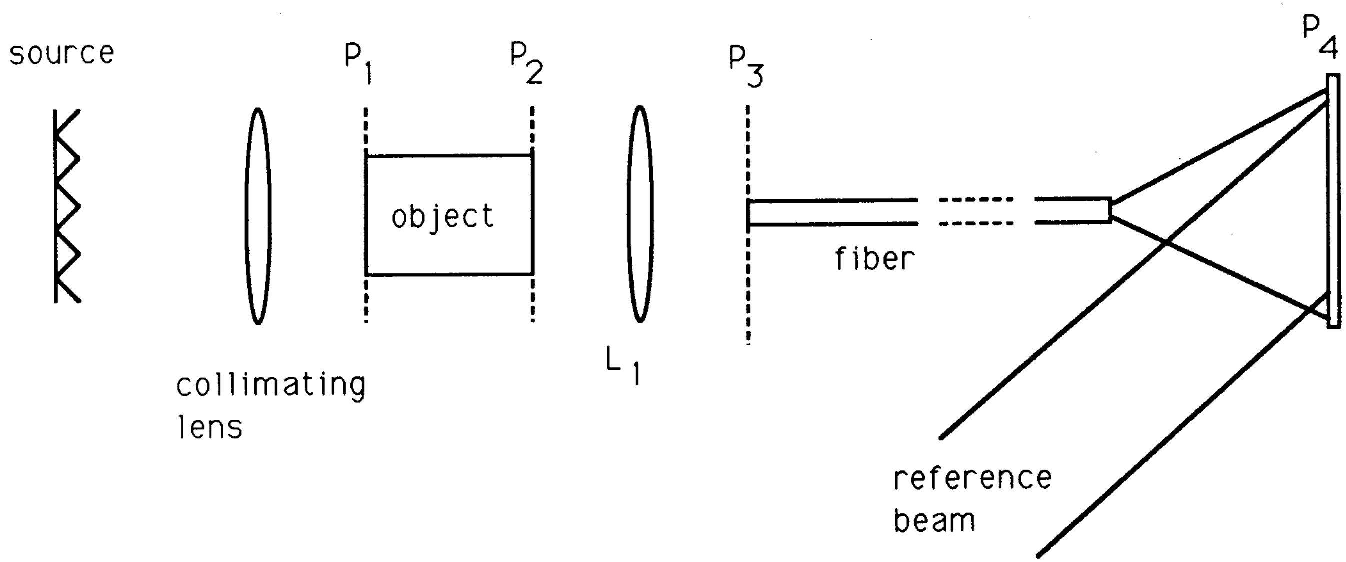

Fig. 1. System for transmitting 3-D images through single mode fiber

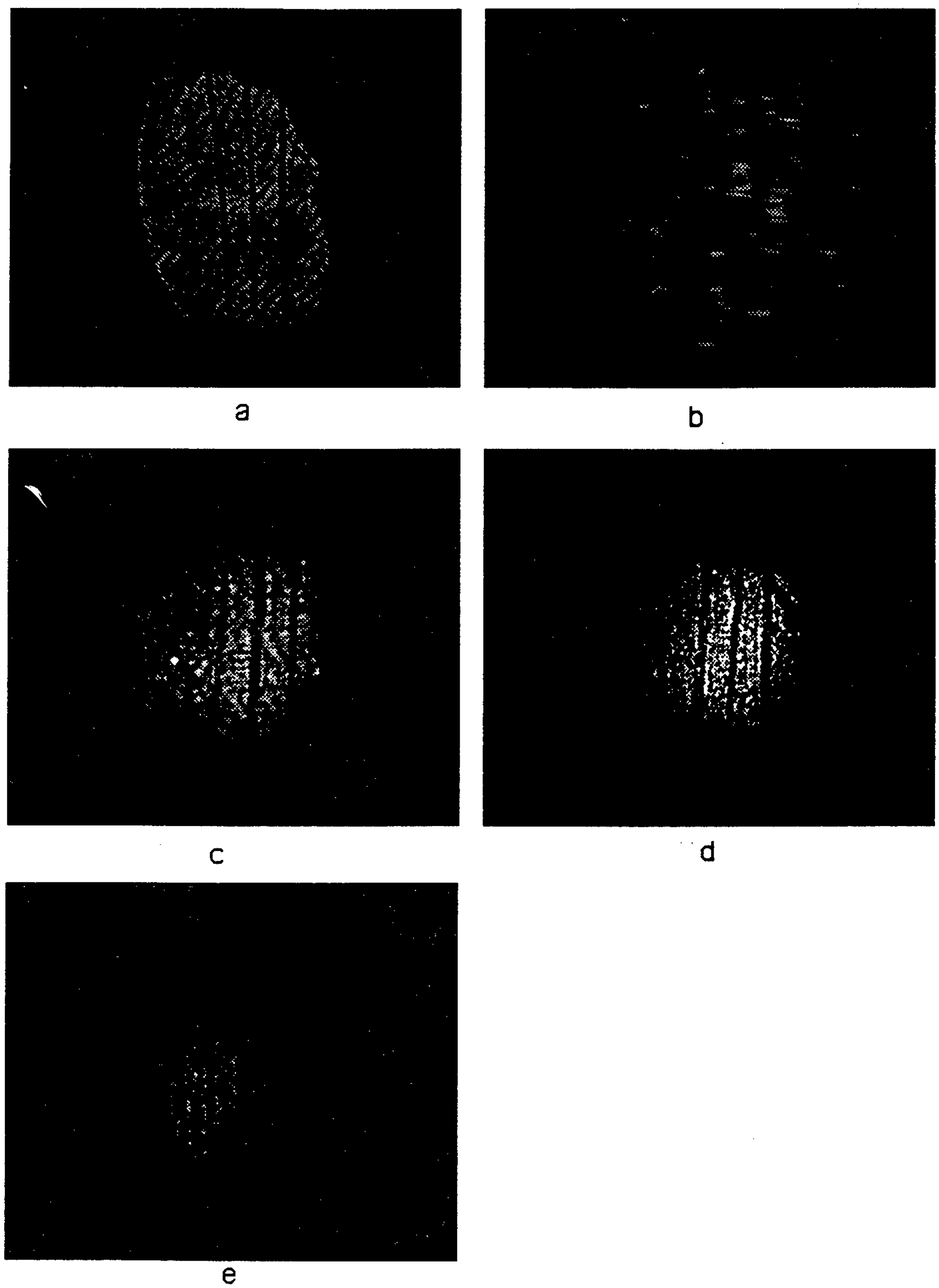

Fig. 2. Experimental results, (a) object (b) Image without holographic process (c) Image with plane 1 in focus (d) Image with plane 2 in focus (e) Image with neither plane in focus.

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